

alteration of the formula used for the determination of the transparency of the atmosphere, was reversed in its course.

Summarizing these considerations, we can say that from the data at hand it can not be concluded with certainty that an 11-month period exists. For this the material available is too scanty. So long, however, as

the 11-month period can not with certainty be proved, it is more reasonable to interpret the facts of observation as an annual variation resulting from terrestrial influences, where the discontinuity of 1925 is caused by the alteration in the reckoning of the transparency, than to assume an 11-month period for which there is no physical explanation whatsoever.

THE CHANGE OF HUMIDITY INCIDENT TO A THUNDERSTORM

By W. J. HUMPHREYS

Anyone who has seen sheets of rain in a thunderstorm vanish wholly before reaching the surface, as they often do in an arid region, and who also has experienced the drop in temperature that accompanies the rain when it does fall to the ground, is quite ready to believe that the relative humidity must increase with the onset of such a shower. And this is just what does happen as the books tell us and the records show.

But how does the absolute humidity, more important than relative humidity in some respects, change with the progress of the storm? The answer to that question, which has been raised in connection with certain lightning-protection problems, is not in the books, nor in the journals either, so far as I could find in a brief search. Recourse therefore was had to original data. Mr. G. E. Dunn, of the forecast division of the Weather Bureau, selected for me a number of typical heat thunderstorms and an equal number of cold-front storms. Then the automatic humidity record of each of these, extending from before its beginning to after its close, was looked up by the division of climatology, Mr. J. B. Kincer in charge.

It was found that (1) in heat thunderstorms the absolute humidity *increases* with the onset of the rain by, say, 15 to 20 per cent, or, roughly, 1 grain of vapor per

cubic foot, or $2\frac{1}{4}$ grams per cubic meter, and (2) that in cold-front thunderstorms the absolute humidity *decreases* in more or less the same proportion, that is, in the order of 1 grain of vapor per cubic foot.

The obvious explanations of these phenomena are:

a. In the case of the heat thunderstorm, since the absolute humidity of the air is approximately the same on all sides of it, therefore the evaporation of the falling rain necessarily increases the vapor density, as does also the contraction due to decrease of temperature, above that either before the onset of the shower or a while after its passage.

b. The distribution of the absolute humidity about the cold-front thunderstorm, however, is quite unequal. It is much greater in the warm air in front of the storm than it is in the cold air to the rear. Here, although the absolute humidity of the air through which the rain is falling necessarily is increased, by virtue of the evaporation that occurs and the decrease of temperature, this gain ordinarily is not enough to raise the vapor content of the oncoming dry air up to, much less above, that of the warm humid air in front of the squall. Hence, in the cold-front thunderstorm the absolute humidity generally decreases with the onset and progress of the storm.

WEATHER TYPES OF THE NORTHEAST PACIFIC OCEAN AS RELATED TO THE WEATHER OF THE NORTH PACIFIC COAST

By THOMAS R. REED

[Weather Bureau, San Francisco, Calif., 1932]

The weather types of the northeast Pacific Ocean are so closely related to the general wind systems of that region that any discussion of them must be predicated on an understanding of what these wind systems normally are and the changes in weather types that changes or disruptions in the normal wind systems bring about. These wind systems correspond in a general way to those found in similar latitudes in the North Atlantic Ocean and may be inferred from the so-called centers of action with which they are associated. One of these centers of action is the semipermanent high which is usually at its maximum between northern California and Hawaii, and the other is the semipermanent low usually somewhere to the northwestward of it. The low reaches its maximum development in winter when the wind systems which accompany it are strongest. The high reaches its maximum in summer due in part to the accumulation of air ejected from the continents of the northern hemisphere at that time of year.

It is sometimes convenient to refer to these so-called centers of action as though they were causative and responsible for the wind systems about them, but for practical purposes such as weather forecasting or the

analysis of weather types it is helpful to recognize them more often as effect than cause and to see in them the indirect but substantial evidence of the set and strength of the accompanying wind systems. In the words of Sir Napier Shaw—

Instead of looking to the centers of high and low pressure as controlling powers, I should propose to regard them as created by the distribution of currents which they have been supposed to control. * * * Thus in the free air low pressure and high pressure, depression and anticyclone, are the marginal effects of the flow of an air current in order to adjust the gradient to the current; the particular shape and intensity of the low and high are conditioned by the distribution of currents in the field.¹

When the high is of ordinary or more than ordinary strength, the orientation of its major axis is the best clue to the classification of the prevalent weather type. When the high is insignificant, the predominant set of the isobars in the low has to be relied on for this purpose. Similar logic governs the interpretation of the weather chart in either case, for whether we are looking at the axis of the high or, in its absence, at the general trend of isobars in the low, we are interpreting the pressure situation which

¹ Quarterly Journal of the Royal Meteorological Society, Oct. 1931, pp. 460, 463.

each reveals in terms of air flow. In this sense the isobaric chart is fundamental and must remain so until some better way is devised for divining the set and strength of the great air streams whose marginal phenomena in the form of traveling depressions are largely determined, as to type and movement, by the parent streams. This system of classification is admirably adapted to weather types of the northeast Pacific Ocean for two reasons: (1) Because the relative uniformity of temperature and equality of level of the oceanic surface permit the isobars to reflect in significant degree the strength and direction of the major air streams in the lower troposphere, and (2) because many of the depressions charted over the northeast Pacific Ocean are high-level (occluded) cyclones whose fronts and discontinuities because they exist aloft, can be located only by inferences from the surface weather map.

Granting that a classification of weather types according to the direction of flow of the major air streams is sound and practicable, it is necessary to adopt a terminology suited to such classification, and to meet this demand the language of Abercromby is acceptable. It will be remembered that he classified England's weather according to the orientation of the isobars on the synoptic chart using the cardinal points of the compass as designators. This plan is well suited to present-day application, especially in the region under discussion; for while Abercromby's classification applied specifically to the types of weather affecting the British Isles, it rests on a conception that is susceptible of much broader application and which can well be adapted to areas of greater extent, especially to oceanic areas where the flow of air masses is unimpeded by topographic obstructions and surface discontinuities of temperature. Furthermore, the suitability of Abercromby's point of view is rendered more conspicuous by the recognition that it evolved from a contemplation of weather types indigenous to a meteorological domain quite similar to ours, the region under his purview fronting on an ocean to the westward in like latitudes from which most of its weather changes are derived. Weather forecasters on the Pacific coast of North America are in a strikingly similar situation, meteorologically speaking, and may well profit from the fertile observations of this astute explorer.

Abercromby's types were four in number, Southerly, Westerly, Northerly, and Easterly.¹ Had his forecast district been larger or lain in more southerly latitudes it is probable he would have found the addition of at least one more type desirable. As it was, the four mentioned were sufficient, and he considered that for his present purpose "a more minute classification would be premature." (*Ibid*, p. 39.) They are not, however, sufficient for a classification of weather types of the northeast Pacific because they ignore two types of importance, one of which—the Southwesterly Type—exceeds all others in prevalence and persistence. But with the addition of this and one other, viz., the Northwesterly Type, Abercromby's types suffice.

THE SOUTHWESTERLY TYPE

The Southwesterly Type, which takes precedence because of its prevalence and persistence, may be considered to represent the normal or characteristic trend of air mass movement over the northeast Pacific Ocean and to correspond in its domain with Bergeron's scheme of the

general circulation of the atmosphere. In this type the two so-called centers of action are oftenest found in the positions assigned to them on the mean pressure charts of the North Pacific Ocean. One is the Aleutian low and the other the North Pacific high. The low extends most frequently from the region of the Alaskan Peninsula southwestward to the Asiatic coast. The high extends from the California-Oregon coast southwestward to and sometimes beyond the middle ocean. It will be noted the type derives its name from the direction of the major axes of the high and low, which are preponderantly in a northeast-southwest direction. The trend of air movement between these two axes must necessarily parallel them and be from the southwest, and the air flow thus predicated probably constitutes the largest persistent interzonal air mass movement to be found in the northern hemisphere.

This type, because of its stability and unmistakable earmarks, affords the clearest and surest evidence of any on the west coast of the coming weather. The high is the distinguishing feature and serves as the best index to the type. Migratory depressions on its polar side travel northeastward to the British Columbian or Alaskan coasts where they die due to the obstruction to cyclonic circulation interposed by the high mountain ranges fringing the west coast of our continent. Such depressions usually reappear somewhere to the eastward, but they seldom cross the mountains intact. The upper wind systems originating or maintaining them do, however, pass over the mountain ranges and reappear as surface lows beyond. "The top," to quote a phrase of Maj. E. H. Bowie, is "sheared off" and passes on, later to appear at the surface somewhere over the continent, while the low-level vortex with its oftentimes violent cyclonic circulation remains west of the mountains and soon fades away. This routine is so habitual with storms of the Southwest Type that it has engendered the epigram "the Gulf of Alaska is the graveyard of depressions." Bergeron described it as a region of "frontolysis," but this is not strictly true, because the fronts presumably exist aloft and pass inland, later to be identified on the synoptic charts as lows of Alberta or Plateau origin. This is an important point for the forecaster to understand, because the appearance of the low "inside" is often a precursor of the decadence of the one at sea. Hence, although a very deep vortex may linger over the ocean, and barometric tendencies on the coast give very dubious indications of its coming demise, if a surface low is seen to be forming inland, the weather in coastal sections which may have been quite stormy is fairly certain to moderate.

It is interesting to note that early forecasters on the Pacific coast believed that storms of this type hit the coast and "rebounded," later to appear and make another try. This view arose from insufficient observational material to the westward. With the advent of the twice-daily pressure charts of the northeast Pacific, its fallacy was revealed. What might formerly have appeared as a recrudescence of the original depression is usually shown by the ocean charts to be the appearance of a new one in the series. Sometimes, it must be admitted, depressions follow each other in such rapid sequence that even charts at 12-hour intervals are scarcely adequate for their detection.

Depressions occurring with this type are usually elliptical, sometimes circular, but seldom V-shaped. The appearance of a V-shaped depression is most likely to be the signal for a change in type to west or northwest.

The sequence of weather in depressions of the Southwesterly Type is practically the same as that incidental

¹ Principles of Weather Forecasting by Means of Synoptic Charts. By Ralph Abercromby.

to depressions of the Southerly Type, and corresponds well enough, in coastal regions at least, with Abercromby's description to make a reproduction of his words permissible:

To the single observer the sequence of weather in this (the southerly) type is very simple. As atmospheric pressure falls, temperature rises, and the sky grows dirtier, till drizzling rain sets in. The wind from some southerly point, having backed slightly, rises in velocity till the barometer has reached its lowest point; as soon as pressure begins to increase, the wind veers a little toward southwest and gradually falls, the air becomes cooler, and the sky begins to clear; but it rarely becomes hard, or contains firm *cumulus*. By next day perhaps the same sequence is repeated, varying only in intensity but not in general character, and this alternation often lasts for weeks at a time. (Ibid. p. 41.)

But while the weather under the governance of the cyclone is similar to that prevailing in the Southerly Type, it does not prevail over so extensive an area. Cyclones belonging to the Southerly Type, according to our classification, would usually affect the weather of the entire coast from central or southern California to British Columbia, whereas those appearing with the Southwesterly Type affect the weather in the higher latitudes only, leaving the region below the fortieth or even the fiftieth parallel under the influence of the "southwest high" and experiencing diametrically opposite weather from that prevailing to the northward. Indeed, as has been said before, the existence of this high-pressure system is the conspicuous feature of the type. In winter its head is oftenest found on the coast somewhere between the thirty-fifth and forty-fifth parallels; the weather on its northern side is mild and cloudy and subject to intermittent cyclonic régimes; that on its southern side is settled and cool. In summer its point of maximum pressure is always at sea and no portion of it ever invades the continent below the fortieth parallel. It is characteristically migratory in winter, with its favorite region of ingress over northern California and Oregon. In summer it is found only over the ocean, except for an occasional invasion of a narrow section of the north Pacific coast, whence offshoots from it sometimes manage to overrun the northern States or Canada.

It is essentially a mechanically induced high in winter, the phenomenon of Humphreys' "mechanical squeeze,"³ produced by the southwest current on its poleward side and the northeast trades on its equatorial side. In summer thermal considerations are paramount. For these reasons it can be remarkably mobile in winter, but is very sluggish in summer. Whenever it invades the continent, either in winter or summer, it tends to produce a continental type of weather on its southern side. Ordinarily the ocean exercises a profound influence on Pacific coast climates—it is wholly in control west of the Coast Range and its sway is more or less apparent as far inland as the summits of the Cascade and Sierra Nevada Mountains or even beyond. Upon the invasion of the "southwest high," however, the oceanic influence dwindles and sometimes disappears even to the coastline itself, and continental control becomes supreme. Thus it is that opposite effects may be ascribed to this high in opposite seasons—in winter it is associated with cold weather on its southern side, and in summer with warm. (Lows occasionally form on its southern side, and these are classified as a subtype of the Easterly Type and are discussed thereunder).

The most remarkable characteristic of the Southwest High is its tendency to intensify over the western highlands in winter where it may lose its mobility and stagnate

for days at a time. Henry has christened this phase of it the "Great Basin Anticyclone."⁴ The Rocky Mountains together with oppositely directed currents in the free air, are its progenitors, the mountains in this case taking the rôle of a northerly countercurrent at their own level and contributing to a "mechanical squeeze" in the lower troposphere that has no yielding on its continental side. The pressure necessarily tends to build up west of the Rockies so long as a south or southwest current runs to the westward of them. This process when supported by appropriate countercurrents at higher levels produces the Great Basin Anticyclone. It may be further augmented on occasion by rapid radiation from the mountains and plateaux, especially when these are snow covered, so that very remarkable barometric pressures may be reached, subsequently to be maintained for sometime after the predisposing causes in the free air have relaxed.

A condition precedent to the breakdown and scouring out of the Great Basin Anticyclone is a shift in the free air winds; they must change from a south or southwest quarter at sea to a west or northwest quarter. The signal for such a shift is often a rise in pressure over the middle or upper latitudes of the middle ocean. If a high appears over those regions with the major axis in a northwesterly direction, it is a sure precursor of the disappearance of the Great Basin High. The deflective horizontal force of the earth's rotation is acting on the air currents implied by the new régime more or less tangentially to the axis of the great western cordillera, instead of at right angles to it, and air accumulation against them instead of being fostered is denied. (Example: Maps of January 4-12, inclusive, 1932.)

SOUTHERLY TYPE

This type might in many instances be fairly well described as the "Southwesterly Type with the high left out." In other words, the low-pressure area covers practically the whole ocean while the high-pressure area appears over the continent with the isobars trending north and south. Individual disturbances developing in the low-pressure field under these circumstances travel almost due north, the predominant air currents being from the south. Abercromby, in conformity to doctrines of his day, referred to those in the Atlantic as "beating up" against the high European pressure and either dying out or being "repelled." His observations on the general character of the Southerly Type show that generically it is the same for both oceans: In it he found that "the Atlantic anticyclone extends very little to the northward, while a large area of high pressure covers Europe to the east and southeast of the United Kingdom. The North Atlantic is occupied by a persistent area of low pressure in which cyclones are constantly being formed. * * *." (Ibid., p. 40.)

As previously suggested, had Abercromby's attention been fixed on the coasts of Spain or Morocco, he might have found that what appeared to the northward as ostensibly a southerly type was related in lower latitudes to a wind and weather situation more closely approximating the southwesterly type, so commonly a feature of the Pacific Coast and Ocean. The essential difference between the Southerly and Southwesterly types, so far as their effect on the weather of the far western portion of the American Continent is concerned is this: The Southwesterly Type, generally speaking, implies contrary weather conditions on the north and south sides of the

³ Physics of the Air, 2d edition, W. J. Humphreys, p. 192.

⁴ Winter Anticyclone of the Great Basin, Alfred J. Henry. Monthly Weather Review, April, 1928.

high pressure head, i. e., moist to the north with temperatures under oceanic control, and dry to the south with temperatures reflecting continental control; whereas the Southerly Type implies oceanic control for the whole coast with rains covering those sections overlain by the rim of the cyclone and mild temperatures everywhere the rule.

The prevailing air movement in the Southerly Type being from the south, eastward movement of cyclones is frustrated. Hence if the low-pressure field does not impinge on the coast, the type may be a dry one for the far western United States and even for British Columbia.

Before leaving the Southerly Type mention should be made for two points in common with Abercromby, both of which have been alluded to in the discussion of the Southwesterly Type. They are brought up again because, as has been said, his Southerly Type doubtless merged into something akin to our Southwesterly Type on numberless occasions. He says, " * * * it is somewhat rare for the center of a cyclone to reach over these islands, so that, generally, Great Britain is on the rim or edge of either a cyclone or anticyclone." (Loc. cit., p. 40.) This corresponds with the observed facts on this coast, that cyclones belonging to the South and Southwest types do not cross the coast line: They move parallel to it in the Southerly Type and disintegrate as they reach it in the Southwesterly. Abercromby says further that "V-shaped depressions are not common with this (the southerly) type." (Ibid, p. 40.) This also agrees with observations of the Southerly Type out here. Indeed it may be said that V-shaped depressions do not occur in the Southerly Type at all. Their appearance, as in the case of the Southwesterly Type, would most likely be the harbinger of a change in type.

This statement, however, must not be understood to exclude the phenomenon of the stationary "trough"; it applies solely to the traveling "V." The stationary trough is a peculiarity of the Southerly Type. When it lies some distance off the coast, the weather throughout the Far West is invariably dry. When it lies along or near the coast the weather is rainy and more or less stormy over the coastal sections and occasionally over the entire Far West. The trough is prolific of relatively small and quick-moving lows which generate in its lower end and travel northward. Sometimes they are clearly discernible on the weather chart, but often are revealed mainly by their effects—warm rains, short-lived southerly blows, and very marked fluctuations in the barometers. A clue to the formation of a new low in the bottom of the trough is found in the following events: if the low that has already formed there and moved northward begins to fill up while barometric pressure in the lower end of the trough remains substantially the same, a new low is certain to develop in the lower end of the trough and repeat the routine of its predecessor. (Example: Maps of December 15–17, inclusive, 1931.)

WESTERLY TYPE

Abercromby found that

in this type the tropical belt of anticyclones is constantly to the south of Great Britain and the pressure to the east, west, and especially the north, comparatively low. Under these circumstances, cyclones are developed on the north side of the Atlantic anticyclone, which roll quickly eastward along the high-pressure belt, usually dying out after they have been detached from the Atlantic anticyclone in their eastward course. Their intensity, and consequently the weather they produce, may vary almost indefinitely. (Ibid, p. 45.)

This is in accordance with observations of the Westerly Type in the Northeast Pacific. In particular it is to be noted that Abercromby found the cyclones occurring with it to be quick-moving, eastward-moving, varying greatly in intensity, and tending to die out over the continent. Self evidently, with the general trend of air currents from west to east as prescribed by the lay of the isobars, cyclones would be required to travel eastward. Their speed of travel, too, consistent with this type of atmospheric circulation, needs no labored explanation. The type lends itself also to the development of a variety of traveling depressions—circular, elliptical, and V shaped, which, in turn, hold forth varied possibilities as to size, intensity, and incidental weather conditions. Their "dying out" as they pass eastward may conceivably be the European counterpart of their tendency in our parts to break up against the coastal mountains.

The effect of Westerly Type depressions on the weather of the Pacific Slope has been described as "tapering." That is to say, their maximum effect is nearest the cyclone path, usually near the international boundary or north of it, while precipitation and wind taper off to the southward. Northern districts may get almost continuous unsettled, rainy weather, with only a brief intermission between one storm and the next, whereas in southern districts the rainy régimes are relatively short and separated by well-marked periods of bright weather concurrent with shifts in the wind from southerly to northerly quarters and conspicuous fluctuations of temperature in conformity therewith. In other words, while northern districts are almost continuously in the belt of low pressure and its eastward-moving depressions, southern districts are almost continuously in the belt of high pressure which suffers inflections of varying degree as the traveling depressions pass along it on the northern side. However, rains in the Westerly Type lows do run well to the south on many occasions, whereas in the Southwesterly Type they are prohibited from doing so.

V-shaped lows and their complementary phenomena, wedge-shaped highs, are features of the Westerly Type, although, as has been said, any kind of depression may be fostered in it. These, however, seem to be a peculiarity of the Westerly Type and of no other. Their behavior is inclined to be very regular, so that if the lines of trough and ridge at sea are accurately charted the progress of both can be timed with fair precision and their arrival on the coast successfully anticipated. Though both tend to lose identity on the weather chart after reaching the coast, their upper wind systems remain in force, and subsequent weather will reflect in the degree that orographic features allow the passage of both trough and ridge aloft. (Example: Maps of December 22, 1931–Jan. 2, 1932, inclusive.)

NORTHWESTERLY TYPE

This type, although not comprised in Abercromby's classification, is an important one in our ocean. It marks a thoroughgoing departure from those which have been discussed and exercises a profound, though transient, effect on the weather of the far western portions of our continent. Consider what its appearance implies. We have seen that the Southwesterly Type represents the customary condition of air flow in the area under review, with its most prominent accompaniment and index the high-pressure system on its equatorial side, the major axis of which lies in a southwesterly direction somewhere between our coast and Hawaii. Now picture this

entire system of air circulation and therefore of pressure as having turned clockwise through an angle of approximately 90° and you will have an idea of what is meant by the Northwesterly Type.

Admitting that the Southwesterly Type is the normal one for this ocean, we can perhaps view the Southerly and Westerly types as merely modifications of it, whereas the Northwesterly Type marks its complete breakdown or displacement. The high-pressure system off the California coast has left its accustomed locus and reappeared with its crest far to the westward and its major axis pointing toward the northwest, perhaps touching the Aleutian Islands or even reaching into Bering Sea. Often it lies in the form of a crescent, one horn near the Aleutians and the other near the central or southern Pacific coast. Depressions, usually elliptical, that are found on its continental side travel eastsoutheast and in winter visit the entire coast with rain. The weather-temperature contrasts provided by the front and rear of such depressions are more marked than in cyclones associated with the types previously discussed—the wind-shift line is sharper and the fall in temperature attendant upon the veering of the winds more pronounced. The type terminates in one of two ways—it either reverts to the southwesterly by a counterclockwise turning of the whole system (in which case the reversion is often sudden, difficult to predict, and presaged only by rising barometers on the Oregon-California coast), or else the high-pressure field drives in behind the eastward-moving low (frequently the last one of a series) giving fairly good warning of this action by the regular eastward progression of the ridge.

A singular and important function of the Northwesterly Type, and one already alluded to, is the invariable premonition it gives of the destruction of the Great Basin Anticyclone if one exists. No matter how intense or persistent this anticyclone may be, it yields to the stress of the Northwesterly Type: usually the dissolution begins at once and is completed in the space of one to three days. (Example: Maps of January 10-13, 1932, inclusive; also October 21-24, 1931.)

NORTHERLY TYPE

The Northerly Type is the converse of the Southerly Type and the attendant weather conditions are alike antipodal. In this type the pressure is high at sea and low over the continent and the isobars run parallel to the coast. It is a very familiar summer condition, at which time it represents a phase of the more or less permanent thermal effect arising from the difference in temperature between the warm continent and cool ocean. When it appears at other seasons of the year it is more likely to imply the operation of dynamic factors which display themselves in unsettled and changeable weather, the most capricious to which the west coast is subject, and characterized by rapid alternations between rain and frost. It is prolific of snows in mountains and plateaux and these often extend into foothill sections. Temperatures are persistently below normal, sometimes dropping to the zero mark in the Great Basin and its contiguous highlands in winter.

The type may occur at any time of the year, but is commonest (summer time excepted) in the spring. Its singular and noteworthy feature is the ease with which (in winter) depressions form on the periphery of the high, i. e., on or near the coast. It has been remarked that, with the Southwesterly Type, cyclones disintegrate on striking the coast, and the monotony of this routine has given birth to the apothegm that "the Gulf of Alaska is the graveyard

of cyclones." A diametrically opposite chain of events is associated with the Northerly Type. Under its sway the Gulf of Alaska, or at least that portion of it near the eastern Alaska and British Columbia coasts becomes (in winter) the birthplace of lows. Lows not only form near the coast line, but are often bisected by it. Presumably in winter, when the Northerly Type is presiding, the northerly air currents running at sea conspire with the mountain ranges paralleling them on the left to abet the formation of depressions, whereas the air currents running at sea in connection with the South and Southwest Types invoke the opposite effect. The deflective force arising from the earth's rotation tends in one case to cause a rise in pressure west of the mountains, while in the other case the same deflective force tends to a fall. Hence, in winter the Northerly Type is prolific of small depressions on or west of the eastern Alaska and British Columbia coasts. In spring the depressions form oftenest over the western plateau. In summer, as has been said, the type is mainly a thermal phenomenon, and although dynamic factors sometimes are of sufficient strength to initiate lows of the winter type they encounter difficulties, as the thermal stratification prevailing at that season is hostile to cyclone development. The type sometimes occurs in the autumn, but is rare.

The type presents much in our domain that Abercromby found in his. He speaks of the low-pressure area over northern and central Europe, while this type is in command, as the theater of formation "of an incessant series of cyclones. The centers of these cyclones always lie to the east of Great Britain, but modify our weather by their approach or recession." He also observed that "the type is most common in winter and especially in the spring months, notably in March; while it is very rare during the autumn." (Ibid., pp. 52-53.)

The type is very conspicuous and the behavior of the depressions incident to it fairly easy to predict, although before the era of vessel weather reports there was much that seemed mysterious about the formation and movement of Northerly Type lows. With no knowledge of pressure conditions at sea it was not understood why some lows, after appearing over the far northwest, would run toward the south and others toward the east. The ocean weather chart has removed to a large extent these perplexities, and it is now easy to understand why, when the major axis of the oceanic high parallels the coast line, lows on the eastern periphery of the high travel southward. (Example: Maps November 24-27, 1931, and December 9-12, 1931.)

EASTERLY TYPE

This type is doubtless less common to the northeast Pacific than to the northeast Atlantic. Abercromby found it "much more common than the Northerly," but this does not seem to be true for our waters. The topography of our mountainous western coast is probably the principal hindrance to its development, although it is undeniably an occasional and very conspicuous feature of our winter weather. It is prevented from developing at all in summer by the combined impediment of west coast mountain ranges and continental temperatures. In its purest form it represents the antithesis of the Westerly Type, which is to say that the belt of high pressure usually lying just north of the Tropic of Cancer has disappeared and been replaced by a low-pressure lane, while a belt of abnormally high pressure is charted to the northward in latitudes more often frequented by

the "cyclone lane" of the Westerly Type. This pressure distribution obviously connotes an atmospheric circulation abnormal to the latitude and one which must be exceedingly difficult to maintain. This fact makes its occasional persistence the more remarkable. It sometimes develops as the dénouement, so to speak, of the Northerly Type, in which case the oceanic high pressure system overruns western Canada while a series of depressions form on its southern side, often in the vicinity of Vancouver Island, and travel south or southeast. Its classical form, however, implies a westward flow of Arctic air across the high natural barriers interposed by the British Columbia and Alaska Mountains. Such a floe, if it succeeds in crossing the mountains, must encounter further vicissitudes in the form of relatively warm Pacific waters. Nevertheless it sometimes is strong enough to negotiate both and push westward over the Gulf of Alaska and occasionally beyond. The region to the southward then becomes one of cyclogenesis, and latitudes ordinarily occupied by the Pacific anticyclone become the theater in which a string of depressions form and travel eastward. These depressions give the Pacific Slope south of Cape Mendocino the wettest, stormiest weather to which it is ever subject, while the region to the northward is visited with the bitterest cold. Indeed, the Easterly Type is emphatically the cold wave type for the Pacific Northwest, and when it merges into a Northerly Type the cold will travel southward and ultimately reach the Mexican border, for the reason that such an eventuality is concurrent with the formation of a depression in the angle formed by the high pressure belt where it turns southward along the coast. This depression, as it moves southeastward, is followed by frigid Arctic air, which under other types of atmospheric circulation has difficulty crossing the mountain barriers and invading the south Pacific Slope. (Example: Maps December 14-24, 1924.)

Depressions of this kind are especially interesting as illustrating the part played by mountain ranges in their origin. In this respect they are akin to lows which form on or near the coast line during a northerly régime, the difference being that winds inducing lows in the Easterly Type blow across the ranges instead of parallel to them. Strong easterly winds in the free air over the Pacific Coast are frequently the precursors of falling pressure at sea and may be the forerunners of cyclone formation in the lee of the mountain systems over which they pass. When the Easterly Type merges into the Northerly, conditions are extremely favorable for a cyclone to develop in the angle formed by the southward bending isobars off the British Columbia Coast. Sometimes a family of depressions will be propagated in this region before the enveloping high closes in behind them and ends the series. It is, of course, the closing in behind the final low that brings the cold weather to the southern coast.

It is not invariable for lows of this category to form over the North Pacific Coast; they may with equal facility form over the Great Basin in the lee of the Rocky Mountains, but this is a spring rather than a winter contingency. Probably in the spring as many form there as farther west. It has been noticed, however, that lows of Great Basin origin belonging to this type are preceded by westerly winds aloft over the southern sectors, countering the easterlies in the free air farther north. This presumably is also a requirement for the formation of similar depressions off the coast, but observations of upper winds offshore are lacking.

Lows of like origin sometimes form over the southern California coast on the tropical side of an overrunning southwest high, or they may lodge there after running south along the eastern flank of a north-south high which, after their passage, presses inland over the Pacific Northwest in a quasi-enveloping movement. In either event the wind structure attending the southwest low is essentially the same, i. e., there are strong north veering to northeast winds aloft over the central portions of the Pacific Slope which are presumably countered by southwesterlies aloft over northwestern Mexico and the adjacent ocean, the latter being clearly implied by aerological data from American sources near the Mexican boundary. So long as this wind structure persists cyclonic conditions persist in the Far Southwest, perhaps with brilliant weather prevailing simultaneously from central California to British Columbia.

This régime is properly an Easterly subtype, even though it develops under a Southwesterly Type high. The weather on the poleward side of the high belongs to the Southwesterly classification, while the weather on the equatorial side of the high has indubitable, albeit small scale, Easterly characteristics. Before the day of regular pilot balloon runs in this region these (subtype) Easterly lows were often perplexing. Their advent seemed fortuitous and their demise conjectural. But the clues afforded by free air data recently available have removed much of this uncertainty. A rule established by these data is: Do not predict clearing weather in southern California while upper winds north of the thirty-fifth parallel are strong from the northeast. (Example: February 13-19, 1932.)

It is perhaps pertinent here to note that when the requisite counter-currents are lacking, the type of pressure distribution just described (an overrunning southwest high) produces, through the agency of the seaward moving air across the mountain ranges in its path, low pressure along or near the southern coast, but without cyclonic developments. Thus, as the high builds up over the Great Basin, the pressure falls to the southwest of it and a trough forms which gradually pushes northward from the region of Baja California to higher latitudes. The falling pressure in its turn requires a descent of the outflowing air of the high, which, warming dynamically as it descends, produces abnormally warm weather in the California lowlands. This is the typical "hot spell" weather type in California in the spring and fall. The high temperatures prevail everywhere at such times, and there is no difference between the interior and the immediate coast, the tempering oceanic influence being entirely annulled. It should be recognized, in contemplating this phenomenon, that the air employed to produce the hot weather in the low lands is not necessarily surface air to begin with; that is to say, it is not necessarily an outflow from the cold substratum of the Great Basin high (which is largely precluded from draining away by the mountain ranges in its path), but may be air of relatively high initial temperature drawn from the inversion above.

In conclusion, brief reference to the late summer and early autumn cyclones indigenous to the waters south and west of Baja California is appropriate, since these disturbances often have a moribund effect on the weather of the Far Southwest. Their habit is to move northward onto the continent somewhere below the Mexican boundary, whereupon they rapidly disintegrate although recognizable in the peculiar "dry-season" rains for which they are accountable in southern California. Until quite recently the origin of these rains was not suspected, but now thanks

to radiographic weather reports from ships off the west coast of Mexico their source has been determined. Even so the problem of forecasting them is fraught with difficulty due to the inadequacy of observational material from the Mexican mainland. If observations from a denser meteorological net covering the states of Baja California, Sonora and Sinaloa, were available, the difficulty would be substantially reduced. (Examples: September 18-19, 1929; September 29-October 1, 1931.)

THE REMARKABLY HEAVY PRECIPITATION AT HENDERSON LAKE, VANCOUVER ISLAND, BRITISH COLUMBIA

By F. NAPIER DENISON

Henderson Lake is situated on the west coast of Vancouver Island, a short distance from Barkley Sound, and at the western entrance of the Alberni Canal, which is a natural channel almost cutting this island in two.

This lake is 20 miles in length and from one-half to a mile in width and lies in a northwest to southeast direction. The rain gage is installed at the Dominion Fish Hatchery at the north end, and is close to a high mountain situated to the north and east of the station.

Though our records show an average annual precipitation on the west coast of this island of over 100 inches, it is interesting to note that at Henderson Lake, which is situated a little more inland, the average annual precipitation during the past eight years was about 250 inches.

The general heavy precipitation on the west coast is naturally much greater at the north end of Henderson Lake owing to its close proximity to a high mountain.

These precipitation observations were started in January, 1923, and in order to show to what extent they exceeded the rainfall at a normal west coast site in the same vicinity, the annual precipitation is shown below for Clayoquot and Henderson Lake for the past eight years.

Annual precipitation			
Year	Clayoquot	Henderson Lake	Difference
	Inches	Inches	Inches
1923	103.32	228.31	124.99
1924	100.30	280.78	180.48
1925	104.21	256.43	152.22
1926	96.25	283.59	187.34
1927	73.59	272.03	198.44
1928	86.57	281.44	194.87
1929	58.19	192.93	134.74
1930	74.09	214.92	139.83
Average for 8 years	87.06	251.30	164.24

From the above figures it will be noted that there is a difference of 164 inches between these stations. Although the precipitation at Henderson Lake was above 280 inches upon three of these years, we must bear in mind that this period is part of a very dry cycle on this coast, as is evident from the fact that the Clayoquot records, which extend back to 1901, show 149 inches in that year and 147 inches in 1902, and from that date to 1911 an almost steady decrease to a minimum of 92 inches. There was then a rise to 1914, from which date to 1921 the yearly average rainfall was 124 inches.

From these Clayoquot figures it would appear that during the past wet periods on the west coast the precipitation at Henderson Lake must have exceeded 300 inches, and that it is probably the wettest recording station on this continent.

The following shorter period falls as derived from the Henderson Lake records are also of interest: The heaviest daily fall was 16.61 inches on December 30, 1926. The heaviest monthly fall was 79.45 inches in December, 1923. The heaviest fall in two consecutive months was 131.98 inches in December, 1923, and January, 1924.

During the first four months of 1931 the total precipitation at Henderson Lake was 154.89 inches.

SNOW ROLLERS

By CHARLES D. REED

(Weather Bureau office, Des Moines, Iowa, January 14, 1933)

"Snow rollers" formed during the night of January 26, 1932, in west central Iowa and were reported from Bagley, Coon Rapids, Stanhope, Laurens, and numerous other localities in southern and western Greene County.

They are balls or rolls of snow formed by the wind, ranging in size from eggs to small barrels, and of such loose and fluffy material that they fall to pieces when one attempts to pick them up. In some way the wind starts a small mass of moist snow rolling along over the snow-covered ground. This mass, at first roughly spherical, gains by accretion of other snow and, if the wind is sufficiently strong, soon acquires the form and size of a lady's muff. The ends usually are hollowed out funnel shaped and sometimes a hole extends clear through lengthwise, though small at the center. From the point of origin to the finished roller there is a distinct and widening track of snow depletion 20 to 100 feet long. From the hilly country south of Coon Rapids some rollers were reported as large as barrels, but, for the most part, the larger ones were somewhat smaller than that. These made "many pastures and fields look as if a host of fairies had rolled thousands of big snowballs during the night." Near Laurens "the balls piled up in places so that a man could not walk among them."

In most of the area where these snow rollers formed there was at sunset of January 25 a hard crust or deposit of old snow ranging from 1 to 20 inches in depth. Moist

snow or snow and rain fell during the night, with the surface temperature slightly above the freezing point. The snow continued on the 26th until about 4 or 5 p. m. and amounted to from 2 to 4 inches. At 7 a. m. (ninth meridian time), January 26, the barometric center of a storm was between North Platte, Nebr., and Goodland, Kans., but it moved rapidly northeastward and passed, between noon and 2 p. m., directly over the area where the snow rollers formed. It was attended by moderate shifting winds, mostly from the southeast through south to west, during the early part of the night of the 26th-27th and to northwest with increasing strength during the early morning of the 27th. The rollers formed while the wind was from the west and the temperatures were falling rapidly, 17° to 23°, and reaching 1° to 15° above zero Fahrenheit by the morning of the 27th.

This phenomenon has been observed, though but rarely, in many of the Northern States. It may escape notice in and near towns where it could be mistaken for the work of children. Photographs of snow rollers at Canton, N. Y., were published in the Monthly Weather Review, February, 1907, volume 35, page 71; also in the issue for July, 1906, volume 34, pages 325-326. Brief accounts appear also in the December, 1895, number, volume 23, page 465; January, 1898, volume 26, page 20; March, 1899, volume 27, page 100.